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Engineering Specification

ACCEPTANCE PLAN FOR INNER TRIPLET DISTRIBUTION FEEDBOXES (DFBX)

Abstract

This specification establishes the requirements and procedure for qualifying the inner triplet distribution feedboxes (DFBX), provided by LBNL as part of the US LHC Accelerator Project, for installation in LHC.

Prepared by :	***Reviewed by :***	***Approved by :***
J. Rasson	**J. Strait**	**Tom Tayolr**
BNL	FNAL	CERN - LHC
JERasson@lbl.gov	**Strait@fnal.gov**	**Thomas.Taylor@cern.ch**

Approval Group Members

Rob VAN WEELDEREN, Ralf TRANT, Vladislav BENDA, Philippe LEBRUN, Karl Hubert MESS, Norbert SIEGEL, Ranko OSTOJIC, Ray VANNESS, Paolo BURLA, Paul PROUDLOCK, Michael LAMM, Tom PETERSON, Phil PFUND, Jim KERBY, Steve PLATE, Tom NICOL

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1. ACCEPTANCE PROCESS

1.1 DFBX ACCEPTANCE BY LBNL FROM THE VENDOR

The inner triplet distribution feedboxes (DFBX) will be built by an industrial firm, under contract to Lawrence Berkeley National Laboratory (LBNL). The specifications provided by LBNL to the vendor are based on the DFBX Functional Specification[1] and Interface Specifications [2-10]. Each DFBX is accepted by LBNL from the vendor after it has been shipped to CERN. Acceptance by LBNL is based on in-process and final tests and measurements performed at the vendor's facilities prior to shipment, which serve to verify the proper assembly and functioning of the DFBX, and tests and measurements done at CERN after shipment, which serve to verify the integrity of the feedbox following shipment. The criteria for acceptance by LBNL are embodied in acceptance travelers, one for each of the six different design variants [11-16], and are summarized in section 2.1 and 2.2 below.

During fabrication, final inspection prior to shipping, or inspection at CERN, discrepancies between measured quantities and the acceptance criteria may be found. These conditions will be discussed among: the vendor, the responsible LBNL personnel, the US LHC Accelerator Project Office (PMO), the official CERN contacts for the US Project and for the Insertions [17]. Disposition may include repair or rework done by the vendor at his facility or at CERN, or by LBNL or CERN personnel at CERN; or acceptance by LBNL of the DFBX with the noted deviation. In the latter case, concurrence on the deviation waiver will be obtained from CERN and the PMO. It should be noted, however, that prompt evaluation and agreement by the PMO and CERN is necessary to allow LBNL to fulfil its contractual responsibilities to the vendor.

1.2 DFBX ACCEPTANCE BY CERN FROM THE LBNL

Acceptance by CERN of the DFBX from LBNL will be based on the tests and measurements performed for the acceptance of the DFBX from the vendor, plus additional tests and measurements, outlined in section 2.3 below, performed at CERN following acceptance from the vendor. If any of these measurements are out of tolerance, or there are any indications of damage in transit beyond those already dealt with as part of LBNL's acceptance from the vendor, the disposition of the DFBX will be discussed among: the official CERN contacts for the US Project and for the Insertions, the PMO, and LBNL personnel. Disposition may include repair and rework, repair done at CERN by BNL or CERN personnel, or acceptance by CERN of the DFBX with the noted deviations. CERN will document its acceptance of the DFBX by memo (paper or e-mail) from the official CERN contact to: the PMO and the LBNL LHC Project Manager and Deputy Project Manager. Once CERN has accepted the DFBX, responsibility for it will be considered to be formally transferred to CERN.

2. DFBX ACCEPTANCE CRITERIA

2.1 CRITERIA FOR ACCEPTANCE OF SUBASSEMBLIES PROVIDED BY LBNL TO THE VENDOR

The tests listed in this section are those which represent the final acceptance tests and measurements of a quantity. Quality control checks and tests, which measure quantities that are measured again as part of the DFBX acceptance process, are not included here.

2.1.1 HIGH TEMPERATURE SUPERCONDUCTING POWER LEADS

Each DFBX contains either two or four pairs of high temperature superconducting (HTS) power leads, rated at 7500 A, which are purchased by LBNL from industry. Acceptance criteria for these are contained in the technical specification for the purchase of the leads [18]. They are summarized here.

<u>Tests performed by the vendor</u>

- Conformity to dimensions on the mechanical drawings, including:
  - o Perpendicularity of lead body with respect to the mounting flange,
  - o Position of the separator seal surface,
  - o Flatness, perpendicularity and surface finish of the separator seal surface,
  - o Overall Length,
  - o Position of 20 K Cooling Inlet w.r.t. mounting flange,
  - o Orientation of warm terminal,
  - o Orientation of mounting flange,
  - o Position of LTS-HTS Connection w.r.t. mounting flange
  - o Orientation of LTS bus bar.
- Pressure Testing with GN_2:
  - o ΔP = 3.4 bar between HTS and resistive sections.
- Leak checking with Ghe:
  - o Between 20 K and 4.5 K section, with ΔP = 1 bar, leak rate < 1 x 10^{-8} torr-l/s (< 1.3 x 10^{-8} atm cc/s).
  - o Upper extremity of the lead, leak rate < 1 x 10^{-8} torr-l/s (< 1.3 x 10^{-8} atm cc/s).
- Hipot test:
  - o Test conditions: 1.3 bar, 300 K helium gas.
  - o 1.5 kV, I < 50 μA.
- Instrumentation Checks:
  - o Temperature sensor continuity.
  - o Temperature sensor hipot: 300 V.
  - o Voltage tap continuity.

<u>Tests of prototype lead pair</u>

- Tests performed at CERN, to qualify the design.
- Tests and results are reported in [25]

<u>Tests performed by Fermilab</u>

- Repeat warm mechanical, electrical pressure and leak tests performed by vendor.
- A complete “qualification” cold test of the first production lead pair:
  - o Resistive section cooling flow rate and HTS warm end temperature in standby

$\leq$ 0.3 g/s per lead of He at 20K, 1.3 bar; warm end of HTS 45 K $\leq$ T $\leq$ 50 K
- o Warm terminal heater power in standby
  No condensation or frost at zero current.
- o HTS-LTS Joint Resistance at 7500 A: $R < 5 \times 10^{-9}\ \Omega$
- o Resistive section cooling flow rate and HTS warm end temperature at 7500 A
  $\leq$ 0.45 g/s per lead of He at 20K, 1.3 bar; warm end of HTS 45 K $\leq$ T $\leq$ 50 K
- o Warm terminal heater power at 7500 A
  T > 12 C without supplementary heating.
- o Pressure drop in 20 K cooling circuit
  $\Delta P \leq 50$ mbar at flow required for 7500 A operation
- o Resistive section is thermally stable at 7500 A with cooling flow decreased 5% from optimal value.
- o Stable operation with HTS warm end T = 60 K.
- o Quench test
  6 second quench delay, 10 second discharge time constant
  $T_{peak} < 200$ K
  No damage to HTS
- o Loss of coolant tests
  No quench following loss of coolant, 5 sec delay, 10 sec discharge time constant.
- o Second cooldown repeats all tests except quench test.

- An abbreviated "acceptance" cold test of the subsequent 19 lead pairs
  - o leads are powered in several ramp cycles to increasing current,
  - o Hold at 7500 A for 3-4 hours to verify thermal stability
  - o Monitor voltages, pressures and temperatures, to verify joint resistance, pressure drop, flow rate, and thermal criteria.
  - o Second cooldown repeats these measurements.

2.1.2 VAPOR COOLED POWER LEADS

Each DFBX contains four assemblies of conventional vapor cooled power leads rated at 600 A or 120 A, which are purchased by LBNL from industry. Acceptance criteria for these are contained in the technical specification for the purchase of the leads [19]. They are summarized here.

- Dimensional checks of the completed assembly
- Full current test
  - o Stable operation at rated 600A or 120 A current
  - o No damage due to 60 sec interruption of coolant flow at the rated current.
- Zero current, full flow test
  - o Warm terminal maintained at T $\geq$ 20 C.
- Hipot test
  - o Test conditions: 1.3 bar helium gas, 4.5 k cold end temperature.
  - o 600 V, I $\leq$ 5 μA.
- Pressure test at P = 4.4 bar.
- Vacuum leak rate < 1×10^{-8} std cc/sec.

2.1.3 BUS DUCT ASSEMBLIES

The bus duct assemblies, which carry the main and corrector busses from the DFBX helium tank to the superconducting quadrupole assemblies and superconducting D1 dipole and the lambda plug, are manufactured by LBNL. The acceptance of the bus ducts by LNBL prior to providing them to the vendor are contained in [20,21]. Those which represent final acceptance tests are summarized here.

- Two cold shocks to T ≤ 80 K, warmed to T ≥ 5C between.
- Pressure test to 2.5 MPa
- Leak rate < 1 x 10^{-9} atm cc/sec.
- Leak rate across lambda plug < 0.1 atm cc/sec with ΔP = 0.75 atm.

2.1.4 INSTRUMENTATION DUCT ASSEMBLIES

The instrumentation duct assemblies, which carry instrumentation leads from the superconducting quadrupole assemblies and superconducting D1 dipole to feedthroughs on the top of the DFBX, are manufactured by LBNL. The criteria for acceptance of the instrumentation ducts by LNBL prior to providing them to the vendor are contained in [22,23]. Those which represent final acceptance tests are summarized here.

- Two cold shocks to T ≤ 80 K, warmed to T ≥ 5C between.
- Pressure test to 2.5 MPa
- Leak rate < 1 x 10^{-9} atm cc/sec.

2.1.5 COLD BORE TUBE ASSEMBLY

The cold bore assembly, which consists of a superfluid helium jacketed cold bore, a duct for connection to the DFBX cryogenic system, and flanges to interface to the LHC vacuum equipment, is manufactured by LBNL. The criteria for acceptance of the cold bore assembly by LNBL prior to providing it to the vendor are contained in [24]. They are summarized here.

- Dimensions are within tolerance.
  - o length.
  - o straightness.
  - o clear bore of beam tube.
- Two cold shocks to T ≤ 80 K, warmed to T ≥ 5C between.
- Pressure tests:
  - o Cold bore to 0.5 MPa.
  - o Jacket to 2.5 Mpa.
- Leak tests:
  - o Cold bore tube leak rate < 1 x 10^{-10} atm cc/sec with jacket at 2.5 MPa.
  - o Jacket leak rate < 1 x 10^{-9} atm cc/sec.

Sections 2.2 and 2.3 are summaries of the acceptance criteria embodied in the Acceptance Travelers for the six DFBX types [11-16]. The section numbers in these documents in which each of the criteria are found are indicated at the heading of each list.

The tests listed in these sections are those which represent the final acceptance tests and measurements of a quantity. Quality control checks and tests, which measure quantities that are measured later as part of the DFBX acceptance process, are not included.

2.2 CRITERIA FOR ACCEPTANCE BY LBNL PRIOR TO SHIPMENT TO CERN

3.1) Helium tank assembly welding
- Manufactured and welded in accordance with ASME Pressure Vessel Code, Section 8, with the exception of final close out weld of excess panel.
- Longitudinal welds radiographed and interpreted.
- Die penetrant test of welds for the helium vessel access panel.
- 4K Charpy impact test: minimum absorbed energy 22 ft-lb (144 J)

3.2) Pressure and leak checks of each piping assembly, after its final weld
- Free of obstructions
  - o Large diameter pipes inspected with bore scope
  - o Small diameter pipes verified by passing a flexible wire or cable
- Two cold shocks to T ≤ 80 K, warmed to T ≥ 5C between.
- Pressure test to the following pressures (Table 3.2)

Pipe Assembly Designation	LBNL Drawing Number	Minimum Test Pressure (MPa)	(psig)
XB+surge pot assy	25I890	0.50	73
CY1	25I210	2.50	364
CY2	25I215	2.50	364
CC'1	25I218	2.50	364
CC'2	25I216	2.50	364
CC'3	25I217	2.50	364
DH	25I225	2.50	364
E1	25I209	2.75	400
E2	25I214	2.75	400
EX	25I212	2.75	400
LD1	25I223	2.50	364
LD2	25I208	2.50	364

- Leak rate < 1 x 10^{-9} atm cc/sec.

4.1) Mechanical inspection at completion of helium vessel and top plate assembly
- Correct position of helium vessel with respect to top plate
- All lead chimney straightness errors < 1 mm.

4.2) Electrical tests after installation of power leads and busses
- Power leads connected to buses per interface specifications
- Continuity of all leads; room temperature resistance recorded
- Each bus labeled with lead designation
- Electrical tests of HTS lead temperature sensors
  - o 50 ≤ R ≤ 70 Ω
- Continuity of power lead voltage taps

- Continuity of He tank instrumentation (LL sensors, temperature sensors, tank heaters)

4.3) Pressure and leak checks after He tank has been closed
- Two cold shocks of He tank to $T \leq 80$ K, warmed to $T \geq 5$C between.
- Lambda plug leak rate ($\Delta P = 0.1$ MPa) = value measured at LBL within 10%
- Pressure test bus ducts to 2.5 MPa for 600 sec with helium vessel at 0.1 MPa
- Pressure test He tank and bus ducts together to 0.54 MPa for 600 sec
- All lead chimney bellows offsets < 1 mm.

4.4) Electrical tests after He tank has been closed
- Hipot leads and busses, temperature sensors, and helium tank instrumentation in room temperature, 1 bar helium
  - o 7500 A leads: 1.4 kV, $I < 15$ μA
  - o 600 A leads: 0.65 kV, $I < 7$ μA
  - o 120 A leads: 0.65 kV, $I < 7$ μA
  - o HTS lead temperature sensors: 120 V, $I < 1$ μA
  - o He tank instrumentation: 200 V, $I < 2$ μA

4.5) Electrical tests after MQX2 and MBX2 ducts have been installed
- Continuity check

4.6) Pressure and leak checks after MQX2 and MBX2 ducts have been installed
- Pressure test MQX2 and MBX2 lines at 2.5 MPa for 1 hour
- Leak rate for MQX2 and MBX2 lines < 1×10^{-7} atm cc/sec

4.7) Hipot instrumentation leads in MQX2 and MBX2 ducts
- Hipot performed in 1 atm room temperature helium.
- Hipot voltages and current limits
  - o Voltage tap leads: 1.4 kV, $I < 15$ μA
  - o Quench heater leads: 1.4 kV, $I < 15$ μA
  - o Warm-up heater leads: 650 V, $I < 7$ μA
  - o Temperature sensor leads: 200 V, $I < 2$ μA

4.8) Electrical tests of DFBX cryogenic instrumentation leads
- Resistance measurement of DFBX temperature sensors: $50 \leq R \leq 70\ \Omega$
- Continuity of leads for temperature sensors on LBX passive heater
- Hipot all instrumentation leads: 200 V, $I < 2$ μA.

4.9) Visual inspection of pipe clearances
- Minimum clearance from any pipe to any other ≥ 12 mm

4.10) Vacuum vessel top plate distortion during end plate welding
- Maximum distortion of center of top plate < 0.75 mm.

4.11) Vacuum vessel top plate distortion during side plate welding
- Maximum at three points along longitudinal center line < 0.5 mm.

4.12) Pipe position and fiducial system measurements.
- All pipe positions within WQX, WBX, JC1 and JC2 ports within tolerances specified in interface specification
- Positions of WBX, JC1 and JC2 vacuum flanges, relative to WQX flange, within tolerances specified in interface specification

- Measurement of fiducials
  - o Positions (x,y,z) of two Taylor Hobson spheres must be measured and recorded
  - o Roll angle of tooling flat (about y-axis, angle relative to z-axis) must be measured and recorded

4.13) Final pressure test of the vacuum vessel
- Hold P = 0.14 MPa for 600 sec

4.14) Final leak check of the vacuum vessel
- Test conducted with helium vessel at LN temperature
- Leak rate < 10^{-8} atm cc/sec

4.15) Final leak check of the helium tank - bus duct circuit
- Includes helium tank, bus ducts (MQX1 and MBX1), HTS leads, and lines CC'1, DH, and LD3
- Helium tank is pre-cooled with LN, then evacuated.
- Helium tank - bus duct circuit filled with Helium at P = 0.12 MPa.
- Leak rate to insulating vacuum < 1×10^{-8} atm cc/s

4.16) Final pressure and leak tests of the piping
- Tests conducted with helium vessel at LN temperature
- XB line tests
  - o Pressure test at 0.44 MPa for 600 s
  - o Pressurize at 0.3 MPa with helium; leak rate to insulating vacuum < 3×10^{-9} atm cc/s
- LD1, LD2, beam tube jacket, E1, E2, EX, CY1, CY2, CC'2, CC'3 line tests
  - o Pressure test at 2.42 MPa for 600 s
  - o Pressurize at 0.3 MPa with helium; leak rate to insulating vacuum < 3×10^{-9} atm cc/s
- MQX2 and MBX2 line tests
  - o Pressure test at 2.2 MPa for 600 s
  - o Pressurize at 0.3 MPa with helium; leak rate to insulating vacuum < 3×10^{-9} atm cc/s

5.1) Pre-shipment inspections
- Visual inspection of shipping crate
- Shock indicators must be zeroed
- Pressure in each circuit must be recorded

2.3 CRITERIA FOR ACCEPTANCE BY LBNL UPON ARRIVAL AT CERN.

5.2A) Visual inspection of shipping container prior to unloading from truck

5.2B) Visual inspection of shipping crate after unloading from shipping container

5.2C) Maximum acceleration of the DFBX recorded during shipment[26]:
- vertical acceleration < 5g
- horizontal acceleration < 2g

5.2E) Vacuum vessel leak check
- Helium tank at LN temperature
- leak rate < 10^{-8} atm cc/sec

5.2F) Leak check of helium tank, bus ducts (MQX1 and MBX1), HTS lead chimneys, and lines CC'1, DH, and LD3
- Helium tank pre-cooled to 80 K
- leak rate to insulating vacuum < 1 x 10^{-8} atm cc/s

5.2G) Helium vessel and bus duct pressure tests
- Pressure test bus ducts to 2.2 MPa ($P_{He\ tank}$ = 0.1 MPa) for 600 sec
- Pressure test He tank and bus ducts together to 0.39 MPa for 600 sec

5.2H) Piping pressure and leak tests
- Helium tank at LN temperature
- XB line tests
  - o Pressure test at 0.44 MPa for 600 s
  - o Pressurize at 0.3 MPa with helium; leak rate to insulating vacuum < 3 x 10^{-9} atm cc/s
- LD1, LD2, beam tube jacket, E1, E2, EX, CY1, CY2, CC'2, CC'3 line tests
  - o Pressure test at 2.42 MPa for 600 s
  - o Pressurize at 0.3 MPa with helium; leak rate to insulating vacuum < 3 x 10^{-9} atm cc/s

5.2I) Instrumentation duct pressure and leak tests
- MQX2 and MBX2 line tests
  - o Pressure test at 2.2 MPa for 600 s
  - o Pressurize at 0.3 MPa with helium; leak rate to insulating vacuum < 3 x 10^{-9} atm cc/s

5.2J-L) Pipe position and fiducial system measurements.
- Coordinate system is defined by measured positions of fiducials
  - o Positions (x,y,z) of two Taylor Hobson spheres
  - o Roll angle (with respect to y-axis) of tooling flat on top surface of DFBX
- All pipe positions within WQX, WBX, JC1 and JC2 ports within tolerances specified in interface specification
- Positions of WBX, JC1 and JC2 vacuum flanges, relative to WQX flange, within tolerances specified in interface specification

2.4 CRITERIA FOR ACCEPTANCE BY CERN FROM LBNL

- All criteria for acceptance by LBNL from the vendor have been met, or satisfactory disposition has been agreed for deviations.

- Hipot leads and busses, temperature sensors, and helium tank instrumentation in room temperature, 1 bar helium
  - o 7500 A leads: 1.4 kV, I < 15 μA
  - o 600 A leads: 0.65 kV, I < 7 μA
  - o 120 A leads: 0.65 kV, I < 7 μA
  - o HTS lead temperature sensors: 120 V, I < 1 μA
  - o He tank instrumentation: 200 V, I < 2 μA

- Hipot instrumentation leads in MQX2 and MBX2 ducts in room temperature, 1 bar helium
  - o Voltage tap leads: 1.4 kV, I < 15 μA
  - o Quench heater leads: 1.4 kV, I < 15 μA
  - o Warm-up heater leads: 650 V, I < 7 μA
  - o Temperature sensor leads: 200 V, I < 2 μA

- Hipot DFBX cryogenic instrumentation leads
  - o Includes passive heater temperature sensors from LBX
  - o 200 V, I < 2 μA

- Continuity of all power leads and busses.

- Continuity of all wires in instrumentation ducts MQX2 and MBX2

- Continuity of all DFBX cryogenic instrumentation leads

3. REFERENCES

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